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DEVELOPMENT OF REMOTE PRESENCE TECHNOLOGY FOR TELEOPERATOR SYSTEMS

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ABSTRACT

The Naval Ocean Systems Center has a broad spectrum research and development program to establish the technology base required to provide remote presence to teleoperated systems. This paper briefly describes the overall program and various key technology areas being pursued. Program direction emphasizes integration of controls and displays with maximum sensory channel communication with the human operator to provide human like work capability and greatly improved efficiency.

INTRODUCTION

The Naval Ocean Systems Center (NOSC) has been engaged in the development and utilization of teleoperated, or remotely manned, vehicles for undersea application for nearly three decades (Talkington, 1976; Wernli, 1979; Wernli, 1982). Ongoing work at the NOSC Hawaii Laboratory is concentrating on the development of teleoperated systems which possess a characteristic which we refer to as remote presence. Remote presence, the perception or "feeling" of actually existing at the remote location, requires careful integration of operator control and display systems with the sensor suit and operational capabilities of the remote unmanned unit. The degree of "presence" achieved is determined by the degree of fidelity of sensory feedback provided to the operator.

Clearly, the relative importance of human capabilities are environmentally and task-dependent; thus, adaptive display and control systems are needed to establish and maintain remote presence. Though many specific work tasks can be performed by telerobotic systems which provide little or no remote presence, such systems are often much less productive when performing complex or novel tasks in unstructured environs. Thus, there is a pressing need to develop systems that can capitalize upon the remarkably adaptive problem solving and manipulative skills of humans. For these reasons our laboratory is addressing theoretical and applied technological problems which must be overcome if practical and more effective teleoperated systems are to be produced.

BACKGROUND AND TERMINOLOGY

The initial interest in remote presence began more than thirty years ago. The nuclear research community needed to protect human operators from the risks inherent with manipulation of radioactive materials. Early efforts resulted in the direct-drive, force-reflective, "telemanipulator" systems which are still in use today. As technology progressed, scientists and engineers tasked with working in the more remote hostile evirons, such as deep sea and space, developed mobile telemanipulator platforms. Although a number of terms have been used to describe a mobile telemanipulator platform which is not directly linked to a master controller (e.g. telechirics, telesymbotics, telemation), *teleoperation* is most often used by current investigators (Johnson and Corless, 1967).

In the early 1970's our laboratory experimented with a helment-mounted, head-coupled television (HCTV) system on an undersea vehicle (Remote Unmanned Work System (RUWS)). The HCTV system, which evolved from previous work at the Naval Weapons Center, China Lake, enabled operators to complete difficult manipulative tasks while hovering in the water column. Experienced gained with the HCTV system, and later demonstrations, showed that remote presence could greatly improve teleoperator system performance.

The Remote Presence Demonstration System utilized a remote unit with a head, arms and torso, and the man-machine interface featuring exoskeleton arm and torso controllers, and a head-coupled display controller described earlier (Hightower and Smith, 1983). This system allowed the operator's head, arm and torso motions to be coupled to the remote unit in real time. Incorporation of stereo vision and binaural audio displays with a head and body coupled torso provided the operator with sufficient remote presence to enable untrained operators to complete difficult tasks to a much better degree than had been expected.

The merits of using remote presence for reconnaissance and surveillance applications using a mobile land vehicle have also been assessed. A radio-controlled land vehicle shown in Figure 1, referred to as the Advanced Teleoperator Technology Vehicle (ATTV), was remotely driven by operators within a vehicle cockpit mockup which contained controls required for vehicle operation and displays for reconnaissance (See Fig. 2). An anthropomorphic head, shown in Figure 3, was placed in the ATTV at the approximate location of the driver's head. The remote anthropomorphic head (controlled in pan, tilt, and roll) was equipped with color TV cameras providing a 60 degree field of view with full overlapping stereo presentation of the area surrounding the vehicle, and binaural audio microphones. A rugged 4 km full-duplex fiber optic cable system provided a non-line-of-sight, wide-bandwidth telemetry system which was inteference resistant. Based upon successful demonstrations in 1985 we have expanded efforts toward ATTV development.

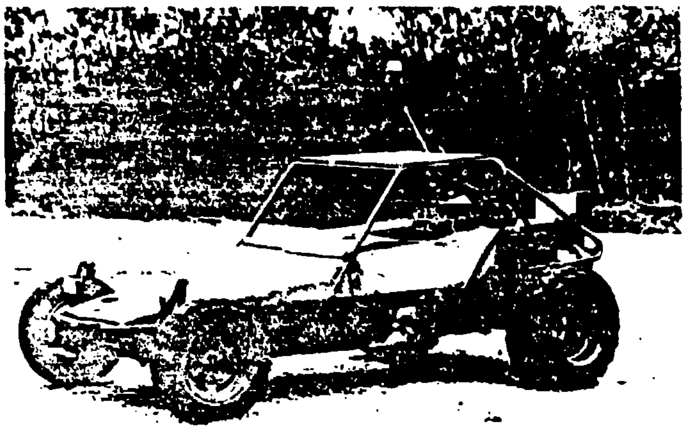

Fig. 1. The Advanced Teleoperator Technology Test Vehicle.

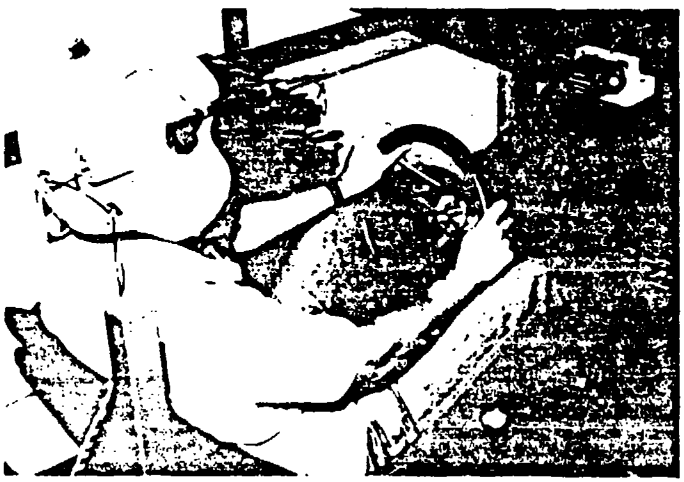

Fig. 2. The ATTV teleoperator's control and display station.

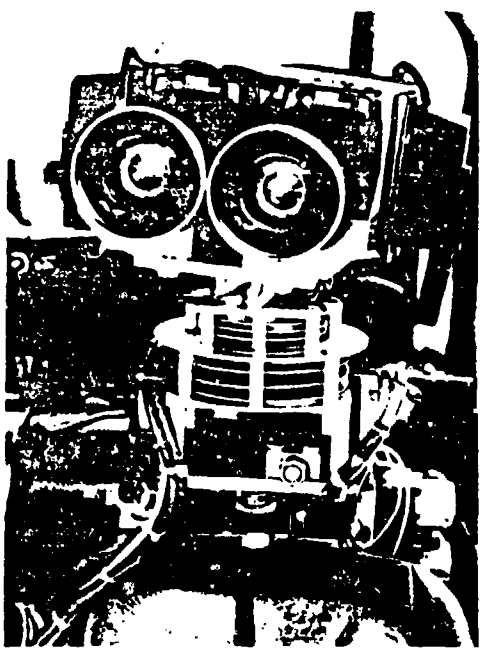

Fig. 3. The ATTV anthropomorphic head containing stereo cameras and microphones.

CURRENT NOSC EFFORTS

In addition to engineering accomplishments, NOSC, Hawaii has been actively pursuing a program of advanced technological development and basic science research in areas which enhance teleoperator capabilities for U.S. Navy and the Marine Corps missions. As part of this program we are pursuing development of a general theoretical model of teleoperator performance which will guide future research and provide a basis of comparison with existing and proposed teleoperator system designs. The following paragraphs briefly describe the ongoing basic science and technology projects at NOSC, Hawaii.

Fiber-Optic Communication Linkages

For a number of years the Advance Fiber Optic Systems Branch has been engaged in the development of deployable fiber optic data links specifically for teleoperator applications. Fiber optic data links are a significant subsystem of teleoperators which are responsible for shuttling bidirectional sensor and control information between the teleoperator and unmanned remote unit. Ongoing research and development efforts are focussing upon advancement of fiber and cable construction, high-speed digital telemetry system design, and canisterization for cable payout.

Present studies of optical fiber design are being supported under a NOSC Independent Exploratory Development (IED) program. Fiber designs have been optimized for the 1.5 micron band and similar results are sought for smaller diameter fibers. To date, a 100 micron diameter optical fiber has been constructed with optical parameters optimized at 1.5 microns.

Needs for cost-effective, deployable, cables and fibers than can survive in hostile environments have driven development of lightweight, Kevlar™ - reinforced designs. Cables with diameters ranging from 1.2 mm to 1.8 mm have been prototyped, wound into canisters, and have been successfully deployed from a variety of vehicles. A major design goal is to achieve uniform application of a suitable elastomer jacket for abrasion and crush resistance of a 1.5 mm cable for improved land vehicle applications. Undersea applications of fiber optic cables has proven to be very successful for data or low power transmissions; however, construction of cables which combine high strength, high power transmission, and large bandwidth capabilities is a major challenge.

Adequacy of current telemetry systems have been challenged as the requirement for stereoscopic video has driven data rates up to and beyond 200 Mb/s. While such data transmission rates are a factor of 10 below the fiber's transmission capacity in deep ocean applications, fiber bandwidth will be the principal limitation facing advances in sensor technology. For this reason we are searching for methods to reduce signal bandwidth requirements for high fidelity sensor suits and controls.

Stereoscopic Visual Displays

Operators of teleoperated systems often use stereoscopic television (TV) displays to provide realistic three-dimensional visual images. Studies thus far have concentrated upon the impact of stereo displays upon operator learning, visibility conditions, and visual task factors which are important to remote manipulation (Pepper, Cole, and Spain, 1983; Spain, 1986). From these studies several conclusions have been drawn. Stereo television displays provide substantial performance advantages over conventional television displays when:

- aspects of the remote scene are unfamiliar or are frequently changing
- rate of learning of new tasks is important
- visibility is poor
- tasks have significant depth positioning requirements.

Following successful demonstrations of stereo television's advantages, the effects of several stereo television parameters on additional perceptual measures such as depth resolution and depth interval estimations were investigated. The stereo TV parameters investigated included:

- camera interaxial separation
- lens magnification
- introduction of motion parallax produced by coupling operator head movements with of a remote pair of cameras.

In all cases, specific values for each of the parameters were found to improve system performance over and above levels typically used in stereo TV viewing systems.

Our scientists and engineers have also developed a hybrid viewing system consisting of a stereo pair of TV cameras transmitting images to a beamsplit polarized display. One eye is presented with a high resolution black and white image. The other eye is presented with a low-resolution color image. All other features of the images (e.g. linearity, brightness, contrast, screen size) have been equalized. Thus, the hybrid viewing system can produce three views depending on the perceptual requirements of the task, the operator's preference, and bandwidth availability: monoscopic black and white with high-resolution, monoscopic color with low-resolution, and a composite color and black and white stereoscopic view with intermediate resolution. Bandwidth can also be adjusted by lowering the frame rate of either or both channels.

Several problems regarding the features of hybrid images and their effects on the operator are being studied. Parameters of immediate concern included:

- video resolution level
- chromatic fidelity
- qualitative and temporal features of retinal rivalry
- potential for retinal rivalry distraction or irritation to the operator
- veridicality of depth perception
- rate of manipulator performance
- production of eye strain, fatigue or discomfort
- judged quality and preference for the system.

Preliminary results suggest that high-resolution black and white information represented to one eye will combine with lower resolution color information to the other eye to produce a stereoscopic percept containing color cues with a resolution level midway between those of the two channels; thus, saving substantial channel capacity. Current efforts are directed toward the formulation of mathematical models for characterizing visual performance with stereo TV displays, selection of appropriate parameters for remote terrestrial reconnaissance, and for the assessment of fatigue effects produces by prolonged usage of such viewing systems. Figure 4 shows the video display, master-slave arms, and stimulus set currently used in the hybrid vision research project.

Fig. 4. Hybrid vision video display, control station, and stimulus set.

Computer Image Processing

Human vision provides an excellent model for computer vision systems that must operate in situations in which operators cannot be present. We are pursuing an extensive program of basic perceptual research in which the visual processes that guide our detection, discrimination, and recognition performance are being measured, described, and modeled Uttal, 1985; Uttal, in press). For this, a simplified visual universe of dotted, three-dimensional stimulus-forms is used in order to avoid complications arising from conflict between different visual cues. The stimulus-forms embedded in random arrays of dots also distributed throughout the three-dimensional viewing space are presented to observers. Upon completion of the appropriate psychophysical experiments, mathematical models similar to those used in the image processing field are developed to simulate the major visual processes and to stimulate the design of new computer vision systems.

A set of empirical "Rules" of visual form perception has been developed that, in large part, have been successfully modeled with mathematical algorithms. A major empirical result is that some forms are much more easy to see than others when obscured by noise. This work is expected to lead in the long run to new computer vision systems for automatic scene interpretation.

FUTURE DIRECTIONS AND PLANS

Teleoperators can perform a variety of tasks in environments or situations where human health and safety risks are high (e.g. military reconnaissance, hazardous material handling or cleanup, fire fighting, damage control, ordinance disposal, deep sea and space equipment maintenance and construction, etc.). Pursuit of improved remote presence will serve to expand the scope of future teleoperations and to improve productivity and utility of existing systems.

To augment our research in teleoperator visual display design NOSC has joined in a cooperative research and development effort with NASA to develop principles for design and construction of tactile display systems for the purpose of enhancing remote presence and manipulative performance in telerobotic systems. Presently a flexible computer-driven virtual arm and tactile sensor display system is under construction. Once finished, the simulator will be used to experimentally determine:

- end-effector force display requirements needed for determination of grasp force and grasp integrity

- sensor blend and resolution requirements needed for reliable discrimination of functional shapes and surfaces of parts or tools

- sensory display priority criteria between tactile, proprioceptor, and visual feedbacks for specific tasks given present and anticipated bandwidth limitations.

In addition to tactile display research, NOSC has begun to study the issue of manipulator actuation in collaboration with DARPA. Under diverse and unpredictable environments destructive impulse loading of heavy and slow remote manipulators is frequently encountered. Under such circumstances actuators, links, or objects manipulated may be damaged. Recent scientific advances suggest that novel materials such as magnetic fluids, polymer gels, and other technologies might be used to produce light-weight, forceful, smooth-acting, durable, and energy efficient actuators. The potential for replacement or augmentation of conventional actuator systems using such exotic materials to produce more "life-like" actuation of telerobotic manipulators is the goal of this newly programmed study.

The Naval Ocean Systems Center, Hawaii Laboratory will continue its basic science and engineering efforts directed toward enhancement of remote presence in teleoperated and supervised autonomous systems. To produce a effective remote presence for teleoperators, as conceptualized in Figure 5, is an exciting and challenging undertaking which offers great benefit to the Navy, Marine Corps, as well as other military and industrial communities.

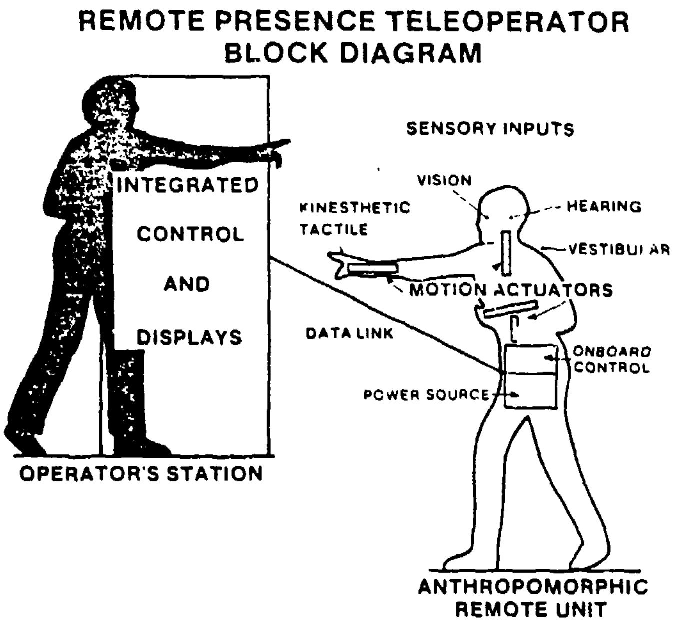

Fig. 5. Diagram illustrating an ideal remote presence system produced through effective integration of teleoperator controls and displays.

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